F^2TE^3: A Transparent semi-monocoque VIP Envelope

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Abstract. This article examines a new lightweight, slim, high energy efficient, light-transmitting, self-supporting envelope system, providing for seamless, free-form designs for use in architectural projects. The system exploits vacuum insulation panel technology. The research was based on envelope components already existing on the market and patents and prototypes built by independent laboratories, especially components implemented with silica gel insulation, as this is the most effective transparent thermal insulation there is today. The tests run on these materials revealed that there is not one that has all the features required of the new envelope model, although some do have properties that could be exploited to generate this envelope, namely, the vacuum chamber of vacuum insulation panels, the use of monolithic aerogel as insulation in some prototypes, and reinforced polyester barriers. These three design components have been combined and tested to design a new, variable geometry, energy-saving envelope system that also solves many of the problems that other studies ascribe to the use of vacuum insulation panels.

Introduction

Energy efficiency is coming to the forefront in the architecture, as, apart from the significance of a reduced environmental impact and increased comfort for users, the current energy crisis and economic recession has bumped up the importance of the financial cost of energy.

Since the Kyoto Protocol was signed in 1997, governments all over the world have been trying to reduce part of the CO_2 emissions by tackling building “energy inefficiency”. In Europe today, the tertiary and housing sectors account for 40.7% of the energy demand, and from 52 to 57% of this energy is spent on interior heating. The new world energy regulations, set out at the European level by the Commission of the European Communities in the First Assessment of National Energy Efficiency Action Plans as required by Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services, [1] indirectly promote an increase in the thickness of outer walls, which, for centuries, have been the only way of properly insulating a building.

The use of vacuum insulation panel (VIP) systems in building aims to minimize the thickness of the building’s outer skin while optimizing energy performance. The three types of vacuum chamber insulation systems (VIS) most commonly used in the construction industry today –metallized polymer multilayer film (MLF) or aluminium laminated film, double glazing and stainless steel sheet or plate, have weaknesses, such as the fragility of the outside protective skin, condensation inside the chamber, thermal bridges at the panel joints, and high cost, all of which have a bearing on on-site construction [2].

Apart from overcoming these weaknesses and being a transparent system, the new F^2TE^3 (free-form, transparent, energy efficient envelope) system that we propose has two added values. The first is the possibility of generating a structural skin or self-supporting façade. The second is the possibility of designing free-form architectural skins. These are research lines that the Pritzker Architecture Prize winners Zaha Hadid, Frank Gehry, Rem Koolhaas, Herzog & de Meuron, among many other renowned architects, are now exploring and implementing.

To determine the feasibility of the new envelope system that we propose, we compiled, studied and ran laboratory tests on the materials and information provided by commercial brands. We compared this information to other independent research and scientific trials on VIPs, such as Annex39 [3], and on improved core materials, such as hybrid aerogels and organically modified silica aerogels, conducted by independent laboratories like Zae Bayern in Germany [4], the Lawrence Berkley Laboratory at the University of California or the Technical University of Denmark.

Theoretical study of the system

Epistemological study of the system: Today both vanguard architecture and the conventional building industry are demanding a constructive system such as is proposed in this research: a lightweight and slim, free-form and seamless, high energy performance system, which facilitates the passage of natural light and natural backlighting and can be used to design self-supporting structures.

After a comparative study of over 147 commercial products and industrial prototypes with each other and against data gathered from studies and independent laboratories, we determined that no system combining all these features exists as yet. Similar systems are not absolutely free form or translucent, are not seamless and/or have a very limited thermal response, among other weaknesses already listed above. The proposed system overcomes these flaws.

Experimental study: We compared the results of the epistemological study with the findings of empirical experiments and computer simulations run on commercial panels and prototypes to which we had access.

Computer simulation: Because of the shortage of information about aerogel and the impossibility of acquiring a sample, we used the DesignBuilder program to conduct a trial by computer simulation under the same environmental conditions as the empirical trials.

Empirical trials

We ran trials to measure the energy performance of the material. These trials were run at the UPM School of Architecture's Department of Building and Architectural Technology using boxes with an inner volume of 60x60x60cm, insulated with 20cm of expanded polyurethane. One of the box faces was left open by way of a window. The study elements were placed in this opening using a specially insulated frame. The trial involved exposing two such boxes to a real outside environment to study their behaviour. The two boxes had two different windows: one was fitted with 6+8+6 double glazing with known properties as a contrast element and the other was fitted with the panel that we intended to study. Data-loggers were placed inside each box for monitoring purposes. There was a thermal sensor on the outside to capture the temperature to which boxes were exposed. The boxes were set in a south-facing position as this is the sunniest exposure.

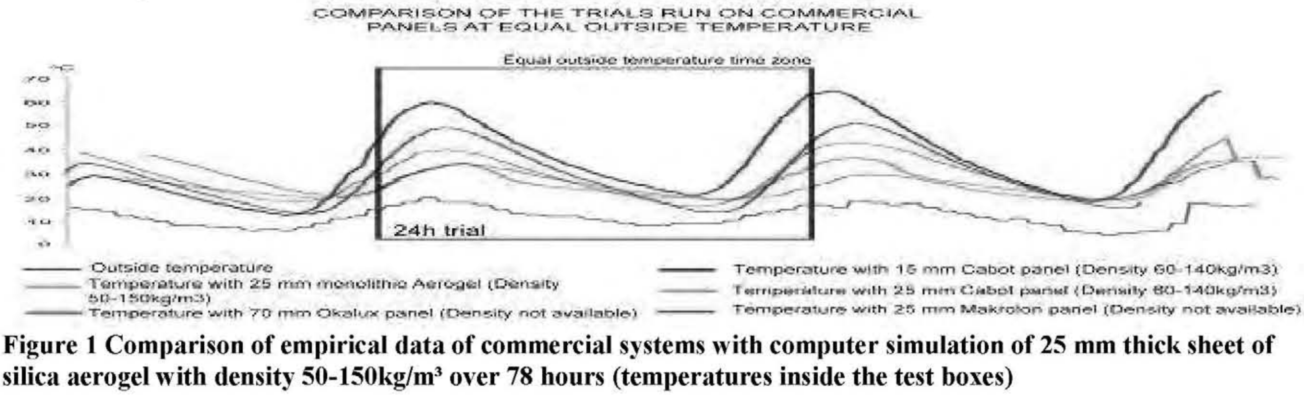

Figure 1 Comparison of empirical data of commercial systems with computer simulation of 25 mm thick sheet of silica aerogel with density 50-150kg/m³ over 78 hours (temperatures inside the test boxes)

We ran 28 temperature-measuring trials using this system, and compared the performance of different thicknesses of commercial panels with 6+8+6 double glazing. Of these trials, the four panels that best combined high light transmittance with a good energy efficiency level were evaluated against the data of the computer-simulated aerogel trial (see Figure 1).

This research confirms that vacuum chamber panels perform better than the other tested systems. It also reveals that, by combining some features of existing elements, such as the vacuum chamber, a core of monolithic aerogel, sandwiched between glass fibre barriers, an innovative system can be designed. This system offers a new free-form, seamless, self-supporting, slim, transparent, high energy efficient VIP envelope, thereby improving on the properties of the VIP panels now on the market.

Proposal for a Free-Form Transparent Energy Efficient Envelope (F^2TE^3)

We propose a free-form design envelope system fabricated with cellulose fibres and polyester resin (or acrylic-based organic resin), and a vacuum core insulated with monolithic aerogel at a pressure of 100hPa. Being a self-supporting component, the system can perform structural functions, and seams between panels are concealed by an outer coating applied in situ.

System specifications: The F^2TE^3 is composed of the dry-seal connection of previously designed male and female edged panels (two female sides and two male sides on each panel that fit together seamlessly). Once the construction is in place, it is given an outer coating of fibers and resins and finally a gelcoat coating to protect the assembly from external agents.

Manufacturing and on-site assembly (Figure 2):

The off-site manufacturing process is composed of the following phases:

a.-An easy-to-use, reusable and ecological molding process. As this does not have to be a structural mold, it can be made of compressed and sanded sheeting arranged according to the panel design.

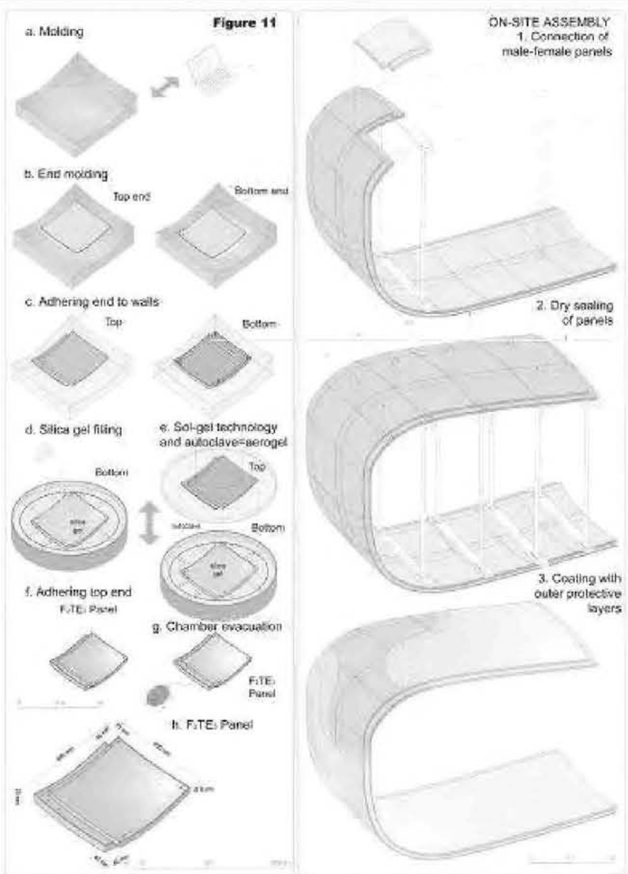

Figure 2 Manufacturing and On-site assembly

b.-The same mold is used to generate the two panel ends and its walls.

c.-The walls are adhered to one of the ends using resin, and the assembly is filled with silica gel, where the panel itself acts as a mold to shape the monolithic silica gel inside the chamber.

d.- Sol-gel technology is used to generate the aerogel inside the panel using an autoclave.

e.-The top end is adhered to the panel using resins.

f.- The panel is evacuated to a pressure of 1hPa inside the chamber.

g.-The panels are transported separately to the site. Scaffolding and props are then used to assemble in situ the panels making up the façade. The panels are screwed together using highly resistant transparent thermoplastic screws.

The system should be manufactured under adequate health and safety conditions.

Testing: A system with a thickness of 25 mm has been computer simulated to examine its energy-saving behavior compared with a computer-simulated aerogel envelope of the same thickness (Figure 3).

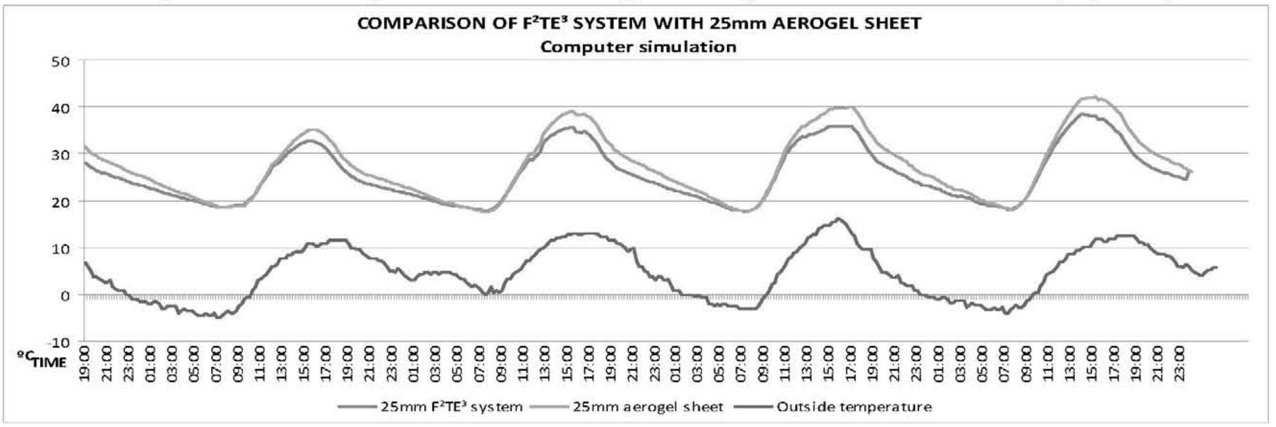

Figure 3 Comparison of a computer simulation of a 25mm thick sheet of silica aerogel with a density of 50-150 kg/m³ with the F²TE³ system over 96 hours.

As shown in Figure 12, although the plots are displaced, the F²TE³ system returns a result very close to what would be achieved with monolithic aerogel without a barrier envelope (not feasible due to aerogel hydroscopy). Even with a barrier envelope, F²TE³ performance almost equals aerogel in terms of heat loss, with a very similar flat curve, where the U value is very small, but results for capture are worse at over 5ºC higher.

Conclusions

F²TE³ is a slim façade system that provides high energy efficiency, with a seamless surface, providing for variable geometry and the option of building self-supporting structures into the same transparent system skin.

Computer-simulated trials have shown it to have almost identical energy efficiency properties to monolithic aerogel systems and VIP envelopes. This system revolutionizes VIP systems, as it generates a transparent envelope but eliminates breakages due to fragility by substituting glass for a reinforced composite material. Additionally, it offers the option of generating variable geometry designs. The prototype F²TE³ system outperforms the systems existing on the market by combining some of the best properties of these systems and overcoming their weaknesses.

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